GLOBAL POSITIONING SYSTEM SHIPBORNE REFERENCE SYSTEM

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LONG-TERM GOAL

The long term goal is to improve the navigation capability of naval vessels using the Global Positioning System (GPS) to the extent that they can be used as a base for differential GPS. This will increase the operational flexibility of the navy in carrying out many of its missions. To achieve this goal, it is desired that a ship be able to obtain and maintain an absolute, stand alone, position of 2 m accuracy or better without inputs from outside elements except the GPS satellites.

SCIENTIFIC OBJECTIVES

The design of a system to improve on the current real time military accuracy of GPS requires an understanding of the characteristics of the various error components that limit the current system. The first objective will be to achieve this understanding in a quantitative way. Various means of overcoming these errors through averaging, use of auxiliary equipment and other information will be investigated and tested. The design, testing and validation of algorithms to implement a 2 m absolute shipborne GPS solution will be an objective.

APPROACH

Navigation using GPS in effect uses a pulsed timing system to find ranges to several satellites. To generate a position one must know the location of the satellites and have an accurate model of the satellite clocks. (Local user clocks are estimated along with the positions.) The current military user accuracy is dominated by the errors in the information broadcast by the satellites on the position of the satellite (ephemeris) and the satellite clock model. These are called the broadcast ephemeris errors. In at sea applications an equally important error is usually multipath, the reception of signals reflected from nearby objects and the sea surface. These are the principle errors that must be averaged down for this system to work. Of course, the motion of the ship will also complicate the this project.

A strawman system to achieve these objectives consists of:

1. Multiple antennas and receivers to use spatial averaging to reduce multipath;
2. An attitude system to assist in bringing together the data from multiple antennas;
3. Atomic clocks to reduce dependence on the satellite clocks in the solution;

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4. Use of a precise geoid and antenna height to improve solutions;
5. Software techniques using phase data to bring data at different times together, even on a moving platform; and
6. Software techniques to average many hours of data from many satellites to reduce the effects of broadcast ephemeris errors.

The approach will be to record both solutions and raw measurement data from high quality military and civilian GPS receivers under laboratory, land vehicle, and ship conditions. Data from example systems of the type included in the strawman system will also be recorded. The data will be analyze post experiment to determine their characteristics and to design a signal processing system to achieve the desired accuracy.

In a laboratory environment controlled multipath sources will be introduced at distances from 2 m to 30 m from the antenna. A antenna tilt table will be used to simulate ship motion with and without multipath sources. For a more realistic motion test, antennas will be mounted on a truck and driven over surveyed tracks. Tests will be conducted on the research vessel PT SUR, a 135 ft vessel based just 20 miles from the Naval Postgraduate School (NPS). All reference trajectories will be generated using dual frequency civilian receivers using post processing. This has been demonstrated to give 10 cm solutions.

The GPS data acquired in these tests consists of solutions and raw measurements (ranges and phases). The solutions generated in military receivers will be based on data corrected inside the receivers for Selective Availability (SA) effects. (This is the intentional error put on the signal to prevent unauthorized parties from achieving full military accuracy.) The recorded raw measurements will, however, include the SA effects. This is done to avoid the generation classified data in a field environment. At NPS the data will be corrected to generate data identical to that present inside an eventual system. This will be done in a GPS Data Correction Facility (GPS DCF). The output of the DCF will be classified.

WORK COMPLETED

During the first year of this project, several experiments have been performed. Two major experiments were performed on the PT SUR. In August 1996, on a student cruise, two Precision Lightweight GPS Receivers (PLGR) were deployed on a single antenna. This is called a "Zero Baseline" experiment. An identical setup was run on shore at a known location. One second solutions were collected for 4 days. Ashtech Z12 receivers were run on the ship and on shore to generate a truth trajectory.

In July 1997 a much more extensive equipment set was taken on a PT SUR cruise. The ship equipment consisted of two survey quality military (PPS) receivers (Trimble SSi's modified for PPS operations), two Ashtech Z12 receivers, one PLGR, two atomic clocks, an inertial measurement unit, an inexpensive attitude system, and a GPS based attitude system. This is essentially a complete complement of hardware from the strawman system. A second setup was run at a shore site, with one receiver of each time.

In addition to the at sea work, there were many data sets taken in the laboratory environment. These concentrated on the effects of multipath. At NPS the GPS laboratory is located just below the roof of the highest building on campus. On this roof there is a series of antenna mounts in a

fairly multipath clean area are used for testing. A 1 m^2 multipath source was used to introduce controlled reflections. There were also truck test conducted with four antennas on its roof.

Work on the establishment of a GPS Data Correction Facility is almost completed. The facility is in place and certification pending from the National Security Agency and the Air Force. The facility is expected to be in service in late CY 97.

RESULTS

From the PT SUR GPS 96 experiment (Clynch, 1997) it was established that the broadcast ephemeris was the major error source in a ship underway. This error can be adequately modeled as a linear function of time, but probably not as a constant. The average effect of this error on horizontal position is about 4 m for each satellite. One key result was the disappearance of multipath error when the ship was underway. This is probably due the roll and pitch changing the relative orientation of the lines of sight of the satellites to the antennas and the multipath sources at a rate commensurate with the loop time constants in the receiver. However multipath is still a factor in dockside data.

Preliminary results from the PT SUR GPS 97 experiment are available. The antenna array used on this experiment is shown in Figure 1. The two Trimble PPS and two Ashtech Z12 antennas belonged to the system under test. Note the large number and variety of multipath sources near these antenna. It should be noted that Figure 1 does not represent an unusual configuration on navy ships. For example, aircraft carriers have over 100 official antennas on the island. There are often more.

There were two 4 day segments to this experiment. On the second segment the discone antenna prominent in Figure 1 was removed. This will provide a good with or without experiment on a major multipath source. Three attitude systems were also tested. Indications are that a simple attitude system may suffice.

Much of the equipment used on these experiments was on loan from other federal agencies. In the upcoming year NPS will acquire its own equipment. This will add to the flexibility of the research.

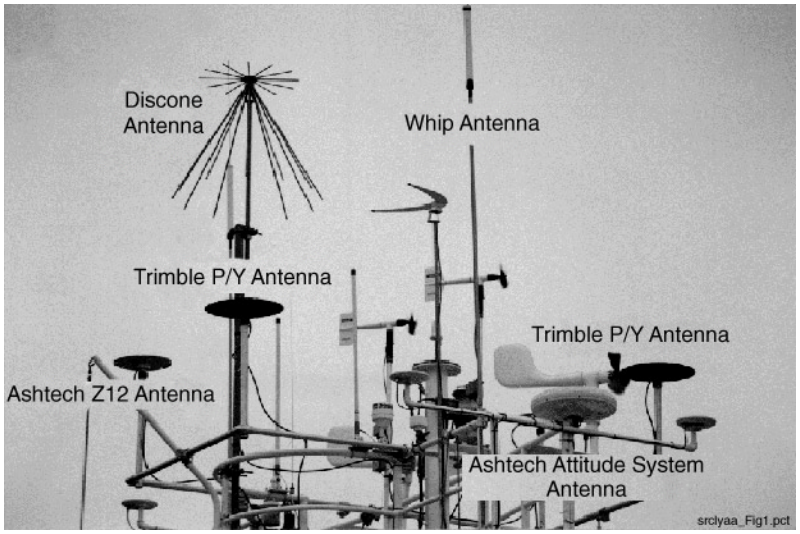

Figure 1. Antenna Array on PT SUR GPS 97 with Multipath Sources

IMPACT/APPLICATION

Establishing a high accuracy position on a ship will enable it to serve as a Differential GPS reference station. This would be of value in mine warfare applications where navigation is extremely important in clearing mines, and in navigating known clear lanes. A force could sail into an area and begin work without establishing ground based reference stations on hostile territory. This work could also be useful to carriers in landing applications and other navy applications.

REFERENCES

Clynch, J.R., 1997."One Meter Positioning on a Ship with PLGR", Proceedings of *ION GPS-97*, Kansas City, September 17-19.